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Visual Display Principles for C^3I System Tasks

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13. ABSTRACT *(Maximum 200 words)*
Modern C^3I systems are best described as semi-automated data management and decision systems over which human operators exercise supervisory control. The effectiveness of such systems is heavily dependent on the design for human-computer interaction (HCI), an important aspect of which is the visual display interface. Current Department of Defense policy mandates consideration of such human factors issues at an early stage in the design process. Comprehensive guidelines are available for display design applications after the general system parameters have been specified. Some recommendations are general, others are specific. This report offers a set of design principles at an intermediate (conceptual) level of abstraction as a complement to existing guidelines. The purpose is to synthesize current knowledge of human cognition into a form that will be applicable to the earliest stages of display design ("cognitive" functions being the most salient and critical of those remaining for the operator in advanced C^3I systems). The principles are derived from a review of the literatures on human cognition, HCI, and display design, some original research, and liberal interpretation by the authors. They are
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organized according to operations performed on specific categories of information in possible C^3I task configurations.

VISUAL DISPLAY PRINCIPLES FOR C^3I SYSTEM TASKS

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VISUAL DISPLAY PRINCIPLES FOR C³I SYSTEM TASKS

Introduction

The purpose of this report is to provide guidance to designers of Command, Control, and Communication Information (C³I) systems for use at the conceptual stage of system development. Its focus is on display design, although optimizing information displays from a human factors perspective demands considering task characteristics as well. Thus it presents a set of display principles organized according to gross operational categories common to such systems.

For the information assembled here to be of practical value in the design process, the user must appreciate the major design issues to which it is addressed, the nature of the knowledge base from which it derives, the rationale on which it is based, and the manner in which it should be applied. The remainder of this section is devoted chiefly to the first three of these considerations; application is reserved for the next section.

Major Design Issues

Modern C³I systems are best described as semi-automated data management and decision systems over which the human operator exerts supervisory control. While individual systems vary greatly in both function and architecture, and all of them can be expected to change dramatically with further advancements in technology, certain characteristics -- and design issues -- are generic to the supervisory control concept (Rouse, 1985; Sheridan, 1987; Sheridan, Charney, Mendel, & Roseborough, 1986). Foremost among them is the importance of effective interaction between human and computer subsystems, a consideration that becomes more rather than less salient with increases in machine capability (Moray & Huey, 1988; Schneiderman, 1987; Sheridan & Hennessy, 1984). The advisability of addressing the interaction early in the design process is now explicitly recognized in military R & D policy as evidenced by the Navy's HARDMAN and the Army's MANPRINT programs (Howell, 1989).

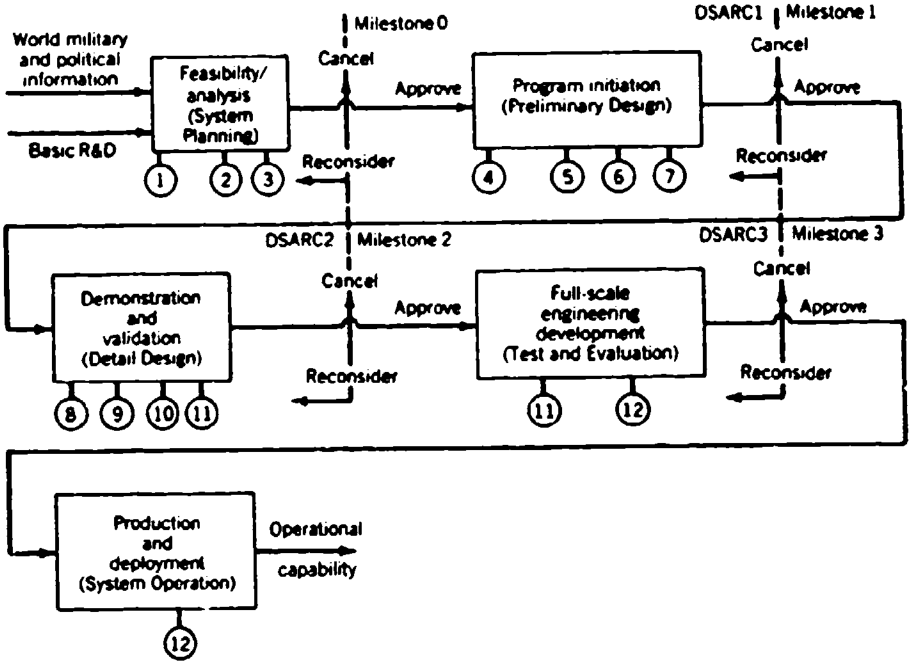
Naturally, the effectiveness of human-computer interaction (HCI) in any such system is a function of enough variables to constitute an entire discipline (Norman & Draper, 1986; Schneiderman, 1987). Despite the frantic pace at which HCI research has proceeded in recent years, however, the number of specific design questions for which there are unequivocal empirical answers is limited (Wickens & Kramer, 1984). Generally they involve narrowly defined tasks common to the widest range of computer users (e.g., text editing, database entry), or narrowly defined components of such tasks (e.g., VDT legibility, query languages). Thus the designer of a specific kind of system does not yet have the benefit of clearly applicable "absolute 'standards' for many system parameters" (Sidorsky, Parrish, Gates, & Munger, 1984, p. 3). One must extrapolate from existing data, estimate the relevance (and comparative importance) of very generally stated "guidelines," reduce such generalities to specific design features, and in the final analysis, rely heavily on educated intuition.

Existing Knowledge and its Application

While absolute answers to these complex HCI issues are thus lacking, there is a considerable, and rapidly expanding, knowledge base from which to derive judicious (if often subjective) design decisions. It comprises three main components: (1) a growing scientific understanding of the human as symbol manipulator and decision maker (i.e., cognitive psychology); (2) an improving grasp of the critical issues and dynamics that characterize supervisory control in general and C^3I systems in particular; and (3) an increasingly useful collection of explicit guidelines for application to narrowly defined HCI design issues (e.g., Engel & Granda, 1975; Sidorsky et al., 1984; Smith & Aucella, 1983; Smith & Mosier, 1986). The present document is the product of a research effort aimed at integrating the first two of these domains for application to design issues of a broader scope than those addressed in the third (i.e., in existing guidelines).

To appreciate this role and contrast it with the function of existing display guidelines, one must consider the process involved in system development. Meister (1985, 1987) describes it as comprising five rational, sequential, but overlapping phases which he illustrates in the flow diagram reproduced in Figure 1. Current guidelines are applicable principally to the detail design phase whereas the present work is directed chiefly toward the preliminary design and even in some cases, the planning phase. The differences are clarified further in the respective sets of questions that dominate each phase (see Table 1). For example, whereas one should consult existing guidelines to determine size, font, and other legibility characteristics of displayed text once the decision has been made to use text, one would benefit most from the present document when deciding whether to use text at all, what information to provide, or whether it is likely to matter enough to justify an experiment designed to resolve the issue. The present document thus focuses on the kinds of variables that have been shown to affect performance of cognitively based tasks, and the general sensitivity of performance on different kinds of tasks to those variables.

FUNCTION/TASK ANALYSIS



1. Mission Profile/Scenario Analysis
2. Function Analysis - Function Flow Diagrams
3. Decision/Allocation Trade Offs
4. Function Allocation Trade Offs
5. Time Lines
6. Operational Sequence Diagrams
7. Task Descriptions
8. Workload Analysis
9. Task Analysis
10. Mockups
11. Evaluation of Man-Machine Interfaces
12. Operational Testing

Figure 1. Phases of the military's system acquisition model. (Modified from Sawyer, Fiorello, Kidd and Prince, 1981.) Note. From Handbook of human factors by D. Meister, 1987, New York: Wiley. Copyright 1987 by John Wiley & Sons, Incorporated. Reprinted by permission.

TABLE 1

Behavioral Questions Arising in System Development

System Planning

1. (Assuming a predecessor system.) What changes in the new system require changes in numbers and types of personnel employed in the previous system?

2. What changes in tasks to be performed will require changes in personnel, selection, training, and system operation?

Preliminary Design

3. Of the various design alternatives available, which is the most effective from the standpoint of behavioral performance?

4. Given a system configuration, will system personnel be able to perform all required functions effectively?

5. Will personnel encounter excessive workload?

6. What factors are responsible for potential error and can these be eliminated?

Detail Design

7. Which is the better of two or more subsystem/component design alternatives?

8. What level of personnel performance can one achieve and does this level satisfy system requirements?

9. What training should be provided to personnel?

10. Are equipment design and job procedures properly human engineered?

Production

Since the questions raised in this phase are primarily the concern of industrial engineering, they will not be discussed in this book.

Test and Evaluation

11. Have all system dimensions affected by behavior variables been properly human engineered?

12. Will system personnel be able to do their jobs effectively?

13. Does the system satisfy its personnel requirements?

14. What design inadequacies exist that must be rectified?

System Operations

15. Do any behavioral problems still exist?

16. What is the specific cause of these problems and what solutions can be recommended?

Note. From Behavioral Analysis and Measurement Methods (p. 9) by D. Meister, 1985, New York: Wiley.

Rationale for the Cognitive Emphasis

Implicit in the above discussion is the idea that considerations involving human cognition are particularly salient in the earliest phases of system design. This is a critical point that deserves a bit of elaboration.

Quite obviously, the principal human factors concern in the evolution of C^3I systems has been the impact of mushrooming machine capabilities on the relatively fixed ability of the human to perform whatever functions remain after automation. So long as the supervisory control concept is maintained, and there is little to suggest that it will soon be abandoned in C^3I systems (Sage, 1981; Wohl, 1981), this will remain a primary focus of both research and design. But as machines become "smarter" and more powerful, the demands on the human inevitably shift and -- unless carefully factored into the overall tasking equation -- not necessarily for the better. Automating everything that can be automated is not necessarily functional (Wiener, 1987). Thus, for example, an operator may seem to be doing little but in fact may be experiencing the deleterious effects of excessive mental workload (Moray, 1982; Moray, Johannsen, Pew, Rasmussen, Sanders, & Wickens, 1979). Or it may be quite obvious that the operator is overwhelmed with "helpful" information supplied by an all-knowing, all-seeing collection of aids; yet despite its precision and timeliness, the information fails to improve system decisions. Or the operator may simply have trouble understanding what the machine is doing, while the machine may fail to appreciate the immediate needs or goals of the human operator -- all to the detriment of system performance. From all indications, the much publicized "Vincennes incident" resulted from a combination of these factors despite the sophistication of the system's technology (Science Agenda, 1988).

Equally as obviously, the kinds of issues posed by such technological advances increasingly involve cognition: human and machine (Norman & Draper, 1986). Therefore, the central concern in C^3I system design reduces to questions of knowledge exchange that include, and perhaps even feature, what are usually considered "higher mental functions": knowledge representation, memory, inference, diagnosis, judgment, etc. This is perhaps best illustrated in Wohl's (1981) summary of problems facing the C^3I system operator that is reproduced in Table 2. Questions involving constraints, risks, options, appropriate knowledge domains, manual take-over, and so forth clearly imply heavy cognitive demands, while the "processing aids" column summarizes the kinds of machine assistance in common use that can either ameliorate or exacerbate these demands depending on how they are implemented.

TABLE 2

Categories of Operational Problems and Processing Aids

Problems	Processing Aids
- Where are my sensors? What is their availability? What is their coverage? What can I see? How old is my data? What is the required sampling rate for each battlefield area, target type, and sensor type, etc.?	(for rapid integration, combination, aggregation, and compression of information):
	- Change detections aids
- Where is the enemy? What is he doing? What is he trying to make me think he is doing? What is his probable intent? What are his capabilities and constraints? What do his doctrine and tactics dictate? What about weather and terrain, logistics, lines of communication, radio-electronic combat, etc.?	- Sensor correlation aids
	- Intelligence correlation aids
	- Bayesian processing aids
	- Zoom in, out with variable detail
- Where are my own forces? What are their current strengths and vulnerabilities? What are their current missions? Can they be diverted? What about weather, terrain, logistics, lines of communication, EW, etc.?	- Speeded-up (i.e., time-lapse) playback of selected battlefield history (by target or unit type, by area or sector, etc.)
- What about special capabilities and employment of RPVs and cruise missiles? Tactical nuclear weapons?	- Pattern recognition aids (location, emitter frequency, number, etc.)
	- Knowledge-based systems

b. Force Planning and Commitment

Problems	Processing Aids
- What can he do next? Constraints?	- Mission planning aids
- What can I do next? Constraints?	- Bayesian processing aids
- How much time do I have?	- Penetration analysis aids
- What are my risks? His risks?	- Fast time simulations
- What are my real options?	- Force allocation algorithms

- What if I do this and he does that?	- Target assignment algorithms
- How fast. . .? How far. . .?	- Optimal control theory algorithms
- What about maintenance or use of reserves?	- Knowledge/rule-based systems

c. Force Direction and Control

Problems	Processing Aids
- Threat warning (SAMs, interceptors)	(near real-time):
- Retargeting	- "If/then" triggers
- Rescheduling	- Optimal control algorithms
- Mission modification/-replanning/restructuring	- Allocation aids
	- Replanning/retargeting aids

d. Distributed Decisionmaking

Problems	Processing Aids
- How to bring expert or special knowledge from geographically separated personnel to bear on a given decision problem	- Mutually accessible displays and data bases
	- Electronic blackboards
- How to achieve a give-and-take environment for discussion and argument in a decision situation in which participants are not collocated	- Electronic maps, pointers
	- English-language data base access
- How to provide a real-time "shared information space" for physically separated personnel	- Graphics-language data base access
	- Special protocols

e. Training

Problems

- Individual decision training

- Team decision training

- Graduated series of exercises with increasing load and sophistication for operators and decisionmakers

- Take over (in operational situation or exercise) by lower-level node of higher-level responsibility due to loss of higher-level node or associated links (a case in which instant on-the-job training assistance may be required

Processing Aids

- Instant replay

- Automated scenario generation

- Automated measurement and scoring (%hits, miss distances, attrition rates, etc.)

- Knowledge-based systems

Note. From "Force Management Decision Requirements for Air Force Tactical Command and Control" by J. G. Wohl, 1981, IEEE Transactions, SMC-11, No. 9, p. 621.

If one accepts the premise that ultimate control will continue to be exercised by human operators (in a "supervisory" capacity of some indeterminate scope), then it becomes crucial to incorporate what is known about human cognition into the design process. The display interface is one obvious point at which such knowledge can be useful. However, a problem arises because the vast basic literature on human cognition is not easily assimilated, and even less easily translated into a form the designer can use. Thus there would seem to be merit in a selective synthesis and translation of cognitive information into a set of design-oriented generalizations.

To be of use in the preliminary design phase any such translation, of course, must take into account the kinds of operations that could be assigned to the human operator (Hitt, 1961). Thus it becomes important to identify and classify generic tasks characteristic of C^3I systems (see next section). The project for which this document represents the final report, therefore, sought to extract from the existing literature on human cognition and HCI a set of display "principles" applicable to component C^3I tasks. Original research was carried out on certain issues for which the available information seemed particularly deficient, and the findings are incorporated into the principles as deemed appropriate. Of course, much still remains to be learned on virtually all the issues, so any undertaking of this sort must be considered provisional, subject to inevitable revision in light of future research.

It should also be recognized that the authors have taken great liberties with the scientific literature in an effort to synthesize useful generalizations. Moreover, in focusing on component operations and visual display features these principles neglect many of the complicating interactive processes that underlie system performance. And finally, simplified though they may be, the principles are necessarily expressed at a level of abstraction above that typically found in design handbooks. It is for this reason that we have chosen to use the term <u>principles</u> rather than <u>guidelines</u> or <u>standards</u>.

The present effort thus represents a compromise between the canons of science and application with respect to issues of display design, viewed from the perspective of human cognition. It seeks to provide the designer with enough insight into the implications of alternative design concepts to avoid serious mistakes, make informed judgments, and identify those issues that can only be resolved empirically. Perhaps most importantly, it aims to alert the designer to the salient human factors considerations (and trade-offs) involved in display decisions.

Understanding and Using This Document

<u>Task Analysis and Description</u>

As discussed above, the most generic description of the operator's task in a C^3I system is that of <u>supervisory control over a semi-automated system</u>, a role that has received a great deal of attention in recent years (Rouse, 1985; Sheridan, 1987). Its essential characteristics are "setting initial conditions for, monitoring and intermittently adjusting, and receiving information from a computer that itself closes a control loop (i.e., interconnects) through external sensors, effectors, and the task environment" (Sheridan & Hennessy, 1984, p. 1). This generic role is composed of a hierarchy of subtasks which, at some level of specificity, defines the unique properties of particular systems. Depending on the overall system architecture, as well as the goals and philosophies underlying that architecture, the human may perform any of a vast array of specific functions ranging from skill-based to rule-based to knowledge-based tasks. In advanced systems, however, the bulk of these activities appears to be in the rule-based and knowledge-based domains (see Table 2). That is, operators follow carefully articulated instructions, or they make judgments and decisions that require some deeper level of understanding of the system and its goals.

The nature and diversity of tasks characteristic of supervisory control, coupled with the fact that virtually all of them are candidates for automation, make any classification problematic. Indeed, at the preliminary (conceptual) stage in system development, the question of which functions to automate is among the earliest to be asked, and how it is answered defines to a great extent the nature of the operator's tasks. Thus if one wishes to provide human performance information for use in the preliminary design phase, one must classify tasks in terms of generic candidate functions rather than the explicit operations characteristic of any existing system. This requires description at a more abstract and molar level than is possible once the system parameters are defined (i.e., in the detailed phases of the design process). Current display guidelines are appropriately more explicit and concrete than the present principles, since their focus is on more clearly defined tasks. It should be recognized that our intent is to supplement, not replace, such guidelines; as noted earlier the two are complementary in both levels of analysis and application.

For present purposes, it was necessary to draw upon four main sources of information in classifying candidate task elements at the desired conceptual level. These included previous taxonomies of supervisory control functions (esp. Baines, 1981; Crolotte & Saleh, 1979, 1980; Meister, 1985; Sheridan & Hennessy, 1984; Williges, Williges, & Elkerton, 1987; Wohl, 1981), written documentation on representative C^3I systems and simulations (AFAMRL/HEC, 1980, 1981; Alexandridis, Entin, Wohl, & Deckert, 1984; Alphascience, 1984; Dept. of the Army, 1983, 1984a, 1984b; Harris, Fuller, Dyck, & Rogers, 1985; Samet, Weltman, & Davis, 1976; Wickens, Kramer, Barnett, Carswell, Fracker, Goettl, & Harwood, 1985; Wohl, 1981), direct observation of several exemplar systems and most importantly, current conceptualizations of human cognition. To appreciate the nature of these concepts as well as the analytic structure to follow, it becomes necessary to consider briefly the way in which human cognition is presently conceived. This is best accomplished with reference to a flow diagram of the sort represented in Figure 2.

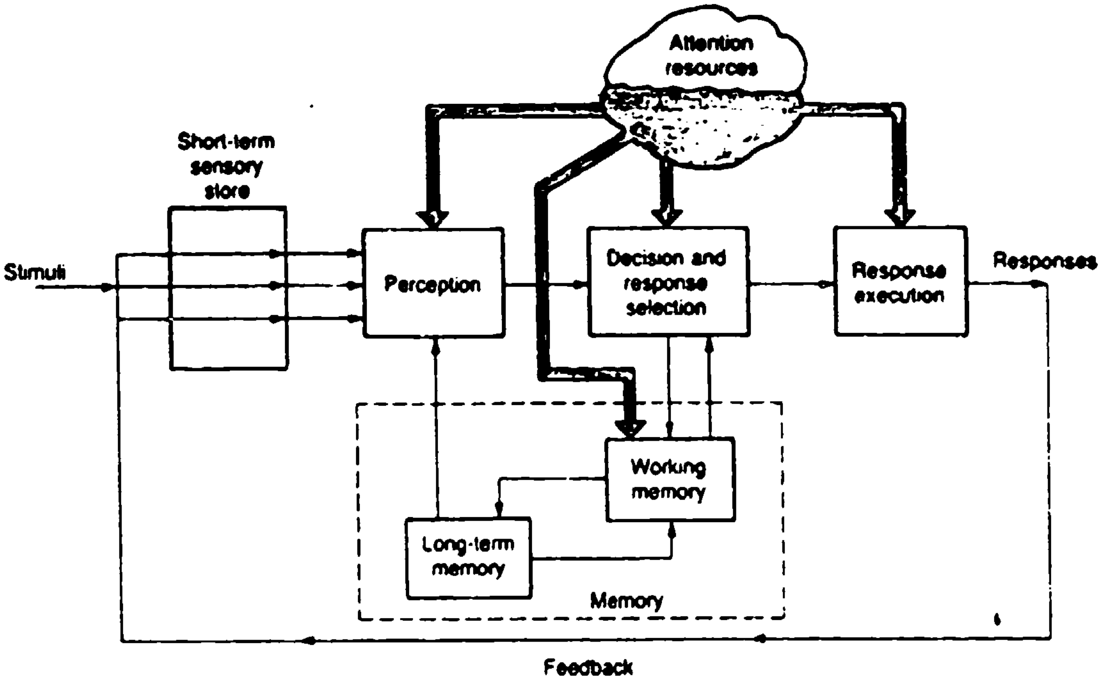


Figure 2. A human information processing model. Note. From Engineering psychology and human performance (p. 12) by C. D. Wickens, 1984, Columbus, OH: Merrill. Copyright 1984 by HarperCollins Publishers. Reprinted by permission.

Basic to this conceptualization is the notion that human information processing involves multiple interactive structures, each of which performs specialized operations on the incoming data. While there is a general directionality in the flow of information (S - R) and an overall serial character to the operations depicted (which contribute cumulatively to the lag and uncertainty observed in the output), both parallel processing (e.g., sensory store - perception) and feedback loops are represented to accommodate the empirical deviations from a purely sequential model.

Superimposed over the entire structural network is an attentional construct to which are attributed both capacity and directional properties. Although controversy still surrounds its precise definition, attention is commonly viewed as a partially allocable mental resource that enhances the efficiency with which targeted operations are carried out. Since it is limited in amount, and perhaps also in allocability, the distribution of this attentional resource governs to a great extent the performance of multiple or complex tasks. Thus it is particularly salient for the more cognitively demanding tasks and informationally rich settings presented by today's C^3I systems. In this regard, an increasingly common assumption is that there are two fundamentally different kinds of processing that the individual may use for particular operations: automatic and control processing. The former places few demands on attentional resources while the latter is "costly." Task design, display complexity, overlearning, and various other factors can determine which process will dominate, an idea having profound implications for C^3I system design (as the principles below will show).

The kind of model depicted in Figure 2 is, of course, only a gross simplification of human cognition, and one that emphasizes the data-driven (or "bottom-up") aspect of the total process. Much of the recent interest in the topic has centered around the equally well-documented and important phenomena subsumed under the complementary top-down processing concept. Virtually every function in Figure 2 (including, as we have already seen, attention) can be influenced by conscious, intentional activity on the part of the processor. As C^3I tasks tend toward the knowledge-based, the top-down aspect becomes increasingly important. If one hopes to assist the operator through decision aiding, display design, training, or by other means, one must first understand how operators (collectively, and in some cases, even individually) perceive the situation. Thus considerable attention has been directed in recent years toward identifying judgment/decision heuristics, perceptual and semantic organization principles, mental models (or schemata) for conceptual problems, and expert knowledge in general. Metaknowledge (or insight into one's processing strategies) is an important component of one's overall store of knowledge.

The principles developed in this report draw heavily upon the basic concepts and material summarized above. Additionally, they incorporate what knowledge we were able to glean from a fairly comprehensive review of the available research on display effects per se that in any way appeared to implicate cognitive processes.

A Conceptual Taxonomy

The mission of C^3I systems is generally to gather and operate on information about salient real events with the purpose of responding in ways designed to achieve specified objectives within an overall plan. Real event characteristics are known to the system only through that information which can vary in amount, precision, reliability, timeliness, complexity, usefulness, and a variety of other ways. Thus a functional description of operator tasks or subtasks necessarily involves information, operations performed on it, and objectives.

Information pertains to four main referents: identifiable events (such as weapons, units, or deployment patterns), context (such as territory, plans, or doctrine), processes (such as rules, aids, and the operations themselves), and objectives (goals or criteria). As noted above, this information can vary in many nonindependent ways, the most important of which are amount, quality, complexity, and usefulness. Unfortunately, only amount (and to some extent, complexity) are readily quantified.

Cognitive operations vary in both kind and complexity, and again, in a nonindependent fashion as discussed earlier (see Figure 2). In fact, they are to a great extent "nested" or hierarchical (e.g., one must remember and identify in order to interpret a pattern of events). Moreover, they are not independent of the information to which they are applied (e.g., interpretation of an event pattern can be virtually "automatic" if the pattern is mapped consistently onto a well-established response category, but it can be a very demanding cognitive process if the pattern is novel or unfamiliar). Given that objectives, too, vary in complexity, specificity, and independence, a comprehensive account of all information-operations-objectives combinations would be neither feasible nor useful for present purposes. Nevertheless, these distinctions were used as a basis for selecting material and deriving generalizations of particular relevance to C^3I systems.

Indeed, all of them are implicated in the following principles, although the taxonomy itself is organized purely according to the operations for which humans are plausible candidates. Thus the reader will encounter many instances in which reference is made to specific kinds of information (i.e., events, context, processes, objectives), and to its amount, quality, complexity, or usefulness.

The conceptual taxonomy is summarized in Table 3. The 18 major categories are organized according to operations in the general order of cognitively simple (and primarily data-driven) to complex (and primarily knowledge-driven). Further definition and illustration of these operations categories is reserved for the next section (which embodies the Principles). Numbers designating each category are expressed with decimals on the expectation that the taxonomy will be expanded and refined (and sub-categories distinguished) as our knowledge grows.

Application

As noted earlier, these principles are intended to provide guidance at stages in the design process before major display parameters -- or perhaps even functions -- have been completely determined. Their proper use can best be understood through a hypothetical example. Assume that designers are in the process of modifying an existing system to take advantage of a new technology through which it is possible to provide greatly enhanced operational status information on system components (e.g., condition of sensors, reliability of aids, etc.). Naturally such information is important to an operator whose principal function is to monitor automated threat diagnosis and retaliation routines and to override or adjust them when conditions warrant it.

TABLE 3

Classification of Major Operations Performed on Information in C^3I Tasks

Simple Extraction
1.0 Read-out
2.0 Identify/Recognize (coded event or object)
3.0 Locate
Complex Extraction
4.0 Discriminate/Compare
5.0 Filter/Ignore
6.0 Perceive/Interpret Pattern
7.0 Correlate
8.0 Monitor
Process
9.0 Remember
10.0 Estimate
11.0 Calculate
12.0 Integrate/Organize/Aggregate
13.0 Evaluate
14.0 Generate/Create
15.0 Choose/Decide
16.0 Manipulate
17.0 Command System
Multiple Operations
18.0 Complex Interaction

Among the decisions facing the design team would be at what level of detail to present this information to the operator (e.g., in terms of overall system status; overall component status; specific facets of component status), whether to provide it continuously or on demand (or which portions to present on demand), how to represent the status information and the event(s) to which it applies (symbols, colors, text, graphs, etc.), and how to integrate it with and distinguish it from other information (e.g., intelligence). Questions of this sort can be answered best by considering the cognitive demands that the various alternatives would place on the operator. Thus, for example, it might be determined that the most critical functions would be monitoring coupled with identification of serious component malfunctions and integration of this knowledge into an overall evaluation of system output.

At this point, the design team might refer to principles 8.0 monitor, 2.0 identify/recognize, 12.0 integrate/organize/aggregate, and 13.0 evaluate. Under each heading they would find a brief definition of the operation category (with specific examples) from which they might judge its relevance for the issue at hand. If the operation were deemed relevant, they would proceed through the carefully selected list of factors that have been shown to have a major impact on its performance. If this list included options that were available to the team, the information summarized in the following "design principles" section would provide general guidance based on the available literature. And finally, if the particular design question called for more detailed information (or if the design team wanted greater assurance that the "principles" were indeed relevant), citations are provided directing the reader to an annotated bibliography of pertinent sources. Often included among these references are the handbooks or "guidelines" documents that, as discussed earlier, contain very explicit display recommendations.

In summary, the "principles" applicable to each designated operation category are preceded in each instance by a definition and illustrations of that category, plus a listing of key display considerations (which are not necessarily in 1-to-1 correspondence with the principles). The rationale for this organization of the material is that it enables a designer to proceed from the general to the specific in a logical sequence based on the best available information. If one is unsure of how to allocate functions, or of which categories in the taxonomy are applicable to a specific design problem, one can easily scan all likely possibilities before getting immersed too quickly in detail. However, one need not rely entirely on the authors' interpretation of available knowledge (which obviously represents a certain amount of judgment). In essence, then, the structure of these principles is designed to encourage a particular <u>approach</u> to the design process which we believe is particularly functional at the preliminary design phase. And it begins with a rudimentary <u>understanding</u> of the display implications of cognitive psychology which we consider necessary for the judicious selection of design alternatives.

Principles

1.0 READ-OUT

<u>Definition</u>. The simplest of "bottom-up" processing operations, read-out, consists merely of responding to clearly-defined, well-recognized events or event features under minimum temporal, spatial, or response uncertainty. Usually involves 1-to-1 stimulus-response (S-R) mapping.

- o Examples: reading text, reporting dial or gauge readings, entering tabled data via keyboard
- o Typical objectives: accuracy, speed

<u>Display Considerations</u>.

- o Image quality
- o Coding -- in particular, S-R compatibility
- o Formatting -- if multiple events are involved

<u>Design Principles</u>.

- o Unless there is a large amount of text to be read or images are difficult to discriminate, performance on most C^3I read-out tasks is relatively insensitive to quality variables above some reasonable level of legibility.

- o More important are coding variables. Insofar as possible, the same information should be represented the same way whenever it appears, and should conform to well-documented coding guidelines (e.g., use "natural language" coding, meaningful symbols or icons, etc.).
- o Formatting is also important and should conform to "natural" response patterns (e.g., reading text from left to right, top to bottom; numbers in columns, etc.) and well-established display principles. Failure to conform to such arrangement stereotypes can result in serious errors.

2.0 IDENTIFY/RECOGNIZE (CODED EVENT OR OBJECT)

Definition. Noting the occurrence of an event and/or identifying it and its meaning from its visual representation on the display screen. The event may require a response or may have to be considered in the context of other events and relevant variables.

- o Examples: identifying an object as friend or enemy, noting that an enemy target has been destroyed
- o Typical objectives: speed, accuracy, or precision

Display Considerations.

- o Amount of display space per symbol (and general economy of space usage)
- o Display quality
- o Coding of events and event features

Design Principles.

- o If the event requires an immediate response, then the display of an attention-getting cue (highlighting, blinking, etc.) until a confirmation of its occurrence is noted can be valuable. Once confirmed, the attention-getting cue should normally be removed so it is not distracting.
- o Identification is much easier (requires fewer mental processing resources) if it can be made on the basis of a single feature rather than a conjunction of features. For example, designating a particular object with a blue triangle involves the conjunction of color and shape which is "costly" in terms of mental demands. Wherever possible, therefore, use different features rather than combinations of features to signify different events.
- o However, it is sometimes necessary to combine features. The most common instance is when there are too many distinct events to permit coding each one separately. Since events are generally composed of multiple features, it is best to code features uniquely which results in multidimensional event or object codes. In these cases (i.e., where multidimensional coding of symbols is necessary) there are several factors to consider:
  Dimensions that consist of only two values are best coded graphically rather than alphanumerically even if there is a relatively small amount of space for each symbol. With up to at least five dimensions (of two values each), graphic coding is as good as (or better than) alphanumeric rating for the goal of efficient processing.
  - When dimensions have three or more values that must be identified individually there often will not be enough space to code them graphically while maintaining sufficient discriminability. Mixed coding schemes with

some dimensions coded alphanumerically and others graphically are often the best solution.

- When feasible, it is better to have all the information about an object in one spatial location rather than spatially separated. For example, it is better to display alphanumeric information next to the graphically coded information than to display it in a text window at the bottom of the display. The exception, of course, is when space limitations combined with amount of information to be presented on each event risk spatial overlap or confusion among events. In that case, all information beyond that needed for identification or other fairly continuous operations should be available only when required (e.g., on demand).

3.0 LOCATE

Definition. Finding and responding to clearly defined events or event features within a well-established context under varying levels of spatial and temporal uncertainty. Generally little uncertainty in response requirement (many-to-1 S-R mapping), but can involve finding a location and reporting its contents (1-to-many mapping).

- o Examples: locating enemy target on a map, reporting the presence or absence of units at a particular location, finding a particular value in a data table, searching for a specified meter reading in a meter bank
- o Typical objectives: speed, accuracy of location and read-out (see also read -out), user acceptance

Display Considerations.

- o Organization and coding of context (formatting)
- o Event coding

Design Principles.

- o If context is physical space (geography), literal graphic coding with labelled coordinates (i.e., map format) is appropriate.
  - An exception is reporting content of specified location, for which tabular organization may be slightly superior; since this would rarely be the only location task, however, its use is seldom justified as the sole display mode.
- o If context is noncontinuous (e.g., set of tactical options, data), organization should conform to some orderly, familiar tabular scheme (alphabetical, numerical).
  - When material is organized in alphanumeric tabular format, performance is affected importantly by the number of groups of characters on the display and the average visual angle subtended by those groups.
  - Contrary to popular belief and most current guidelines, performance is not seriously affected by the spatial uncertainty of rows in a tabular format, provided the same format is used consistently (i.e., the table need not be left-justified).
  - Different equations are necessary to predict performance and user preference in tabular formats. For example, users strongly prefer low spatial uncertainty (left-justification) even though they perform just as well under high uncertainty (see above).

- Whether preference and performance functions become more congruent with extended practice is an open question that deserves research.

o If context is temporal, graphic (time line, window, clock) representation is appropriate where only moderate precision is required; digital coding is necessary for precise location.
  - Graphic coding imposes less processing demand on the operator than does digital coding, especially if temporal intervals are to be represented; thus graphic display interferes less with concurrent operations. One cannot read a digital display "approximately" -- thus it forces excessive processing for certain objectives.

o Whatever its organization, the most critical feature in context representation is its <u>constancy</u>: Changes hamper information location.
  - Changes under the operator's control that do not alter the basic organization, such as scrolling and zooming, do not violate this principle.

o Distinctions among context categories (map zones, option categories, etc.) superimposed upon the basic organization should be used sparingly and coded with great care, especially if they involve any overlap.
  - The potential problem is that of increasing the uncertainty and complexity associated with each context site which can slow response selection and increase location errors. Also, each coded distinction adds to the overall display "clutter."
  - Color coding of spatial distinctions can create an undesirable three-dimensional effect when zones overlap.

o Events should be coded for ease of location only after considering the other operations to be carried out on those same events, and judging their relative importance.
  - The potential problem is that conflicting principles are often involved. For example, distinctiveness of coding features aids location of a <u>particular</u> event but hinders recognizing that event as a member of a <u>class</u> of similar events, or perceiving it as part of an event <u>pattern</u>.
  - Since location per se (i.e., for unequivocal events) is a very robust human skill, the specific event code is not as critical as it is for other functions. When, however, location is combined with other operations (esp. filtering, monitoring) coding can become very important.

o The most critical consideration in coding events for location is lack of variation in the representation. The more uncertain the operator is of the appearance of the target event, the poorer performance will be. If, for example, alphanumerics were used, case and font should not be varied unnecessarily.

o All else equal, color is the most effective single cue for event location, followed by shape.
  - In color coding, however, a limited number of elements can be used (see also <u>identify/recognize</u>), and both operator color vision (color weakness, adaptation state) and viewing conditions (luminance, contrast, etc.) must be considered.

4.0 DISCRIMINATE/COMPARE

Definition. Judging the similarity or identity of two or more events (objects) or of an event with a standard. May include events' histories or trajectories. Judgments may be based on a specific feature, a subset of features or all features of the events.

- o Examples: judging the relative speed of two units; comparing the severity of the threat of two or more units; comparing targets in terms of time left in range
- o Typical objectives: speed, accuracy, economy of space usage

Display Considerations.

- o Precision of information to be displayed
- o Coding and formatting (graphic versus alphanumeric)
- o Display resolution

Design Principles.

- o Highly salient dimensions (features) may block attention to less salient dimensions making discrimination of less salient dimensions difficult. For example, noting the more rapidly advancing of two enemy units may reduce the likelihood of distinguishing them in other respects (recognizing differences in composition or strength).
  - When secondary, tertiary, etc. features are of critical importance, or when multiple features are of equal importance, each feature should be represented separately and comparatively (as, for example, in bar graphs or uncluttered tables). (See also identify/recognize.)
- o If comparisons of values based on the height of a bar indicator are to be made, it is desirable to have the bases of the bars at the same level.
- o If symbols are to be compared, the context within which they appear can affect the perception of relative values of their dimensions. For example, comparisons of the brightness of stimuli appearing in areas with differences in local brightness are very difficult and subject to error.
- o Weber's law (\|F(Æ I,I) = k) should always be considered in using continuous stimulus dimensions (e.g., intensity, size) to represent event features. This law states that the perceived magnitude of any increment in stimulus magnitude (Æ I) is directly proportional to base magnitude (I) and implies a logarithmic relation of perceptual to physical magnitude (a relation that holds over practically important regions of most sensory continuua). (See any standard reference on human sensory processes or psychophysics.)
  - It is important to realize that far fewer levels of any stimulus dimension (usually 5-7 at most) can be used for coding if the operator must distinguish events in the absence of direct comparison (i.e., must identify/recognize rather than discriminate/compare events).
- o Graphical or analog representations are usually desirable if comparisons are to be made between the present state of an object and a previous state.
- o Some dimensions are perceived holistically (such as heights and widths of rectangles) and therefore one should not require comparative judgments based on these dimensions individually. For example, one would not want an operator to compare the heights of two events that differed in width.

- o When certain values of a dimension on which two events are being compared are of critical importance, then it is often valuable to add an extra coding dimension when critical values of that dimension are reached. For example, one factor in choosing which of two targets to fire at first is the time left while it is in range. Rather than code this variable simply numerically or with a bar graph, performance can be improved by adding color coding, for example, to indicate that the time left is critically low.
- o Any event that is to be noted in a display in which there are many other objects should be discriminable from other objects on the basis of a single feature such as color (see also filter/ignore).
- o Discrimination issues become most critical under conditions of high operator workload (time pressure, decision criticality, display information load, etc.) due to restriction in available "processing resources." Thus confusions can occur among coded events that seem almost impossible to confuse under less stressful circumstances. However, coding principles that promote ease of discrimination/comparison often detract from other operations (e.g., integration/organization/aggregation). Therefore, it is well to consider carefully the cost/benefit potential for any proposed coding scheme over all likely operations.
  - If the potential cost of discrimination errors is extremely high (as in cases where integrative functions are largely computerized), every effort should be made to promote "automatic processing" in discrimination (see also filter/ignore). Otherwise, it may be preferable to emphasize the commonality of events at the expense of discrimination in the coding scheme.
  - There is often no a priori bases for distinguishing among candidate coding schemes insofar as the discrimination-integration trade-off is concerned. An empirical test under representative task conditions is the only defensible approach. This is an area in which investment in research can pay huge dividends in ultimate system effectiveness. (See also complex interaction.)

5.0 FILTER/IGNORE

Definition. Intentionally disregarding or paying limited attention to displayed information that for present purposes is minimally relevant. May include events, event features, or context which are relevant under other circumstances. Usually involves effortful "control" processing, and is a major source of degraded performance under heavy display load or "clutter."

- o Examples: ignoring units that pose no threat during an engagement, disregarding messages to neighboring command centers, ignoring data in tables that are not presently needed for the task, directing attention away from friendly units that have entered protected zone
- o Typical objectives: avoidance of error, conservation of "mental resources" for efficient processing of relevant information

Display Considerations.

- o Total amount of information displayed (load)
- o Coding

o Formatting

Design Principles.

o Minimize the amount of supplementary, redundant, and infrequently-used information displayed continuously, making judicious use of operator demand (call-up) feature (see complex interaction, below).

o Observe coding and formatting principles for identify/recognize, locate, and discriminate/compare operations. In particular:
- Use common selective highlighting cue to distinguish currently relevant or important from less relevant items.
- Minimize the use of conjunctive coding in graphic symbols.
- Organize tabular material according to priority where feasible (i.e., using spatial location as filtering cue).
- When an event or event-feature class requires constant or frequent attention, vary its coded representation as little as possible in satisfying other operational requirements (consistent coding will push filtering demands in the direction of skill-based or "automatic" processing, thereby reducing "mental resource" expenditure).

6.0 PERCEIVE/INTERPRET PATTERN

Definition. Recognizing unique combinations of events or event features as having diagnostic meaning, under varying levels of spatial and temporal uncertainty. Generally little uncertainty in response requirement once pattern is interpreted (1-to-1 S-R mapping) although interpretation can proceed in part serially (i.e., as a progression of interpretations as more information is revealed).

o Examples: recognizing whether a particular configuration of tracks represents a deployment of forces against a particular resource, recognizing whether a change of location or configuration over time represents a threat to a particular resource

o Typical objectives: accuracy, speed

Display Considerations.

o Clutter in the display

o Organization and coding of "figure" vs. "ground"

o Representation of temporal information and information about change

Design Principles.

o Accuracy and speed of recognition will be enhanced if the displayed events closely resemble the operator's mental representation.

o If the pattern is a function of spatial relationships between tracks or units and a background (figure and ground) then literal, graphic coding is appropriate. A three-dimensional representation of the background could enhance pattern recognition.

o If the pattern is a function of spatial relationships only among tracks or units, then the ability to dim or erase the background could enhance pattern recognition.

o If the pattern is a function of changes in locations or relationships over time, the ability to view a time-lapsed playback of tracks or units, by track type, could enhance pattern recognition.

- o The ability to display prototype patterns which resemble the display situation may serve as a memory aid to reduce mental workload and enhance pattern recognition.
- o Critical combinations of events or event features should always be represented in exactly the same way and have the same meaning across prototype patterns in order to allow operators to develop the ability to detect them "automatically."
- o Some people tend to process pattern information more holistically and others do so more analytically.
  - The more the displayed pattern differs from the prototype pattern, the more this will affect speed of recognition for those who process analytically; but will not affect response time for those who process holistically.

7.0 CORRELATE

Definition. Detecting similarities or other relationships in the actions of events represented in different spatial locations.

- o Examples: detecting a common change in direction of planes in different areas that might indicate a concentrated attack on a specific target, detecting simultaneously occurring unexpected events that together might reveal a coordinated plan
- o Typical objectives: reveal patterns that could easily go unnoticed

Display Considerations.

- o Coding of "figure" and "ground"
- o Aiding techniques

Design Principles.

- o When an operator wishes to look for a possible correlation in events, it should be possible to hide the display of irrelevant objects and replay the trajectories of the objects in question at an appropriate speed (see also filter/ignore).
- o Optional color coding of classes of objects to be correlated can facilitate the detection of correlations.
- o Data smoothing algorithms can help reveal regularities underlying correlations.
  - Humans are not particularly adept at either recognizing or estimating correlations, and are likely to make large systematic and non-systematic errors in doing so. Wherever possible, machine aiding should be provided (e.g., to calculate and display precise statistical indexes rather than "raw" data points).
  - The concept of correlation is itself not easily grasped by the statistically unsophisticated operator. The tendency is to infer causation (whether or not it exists), and to interpret indexes inappropriately (e.g., correlation coefficients as percentages). Hence particular attention should be given to the sophistication of potential users in determining how to represent correlational data.

8.0 MONITOR

Definition. Scanning a defined context or event set or observing an automated process for the purpose of detecting critical changes or conditions (usually called signals). May involve well- or poorly-defined signal conditions, varying amounts of spatial and temporal uncertainty, and extended periods of observation. Signals are usually infrequent.

- o Examples: monitoring process control panel for conditions that exceed tolerances, operating sonar or radar detection systems, ensuring that tactical maneuvers are proceeding according to plan
- o Typical objectives:
  - timely detection (short latency)
  - accurate response (high detection rate, low false alarm rate; conformance with desired response criterion for signal detection)
  - sustained performance (minimization of the "vigilance decrement" over time)

Display Considerations.

- o Formatting
- o Event and signal coding
- o Attention enhancement techniques

Display Principles.

- o When multiple discrete information sources are monitored and graphic coding is used, display of those sources or information channels should be organized in symmetrical matrix form. Common examples include banks of gauges, dials, multiple bar graphs representing event status at various sites, and multiple "pie charts." If the number becomes large enough such that, given sufficient size and spacing, considerable visual scanning is required, symmetry should be violated in favor of the horizontal dimension.
  - Symmetry should be observed up to perhaps 16 channels (4 x 4 matrix) since with proper coding it is possible for the operator to process such an array with minimal eye movement and considerable automaticity (parallel processing).
  - Horizontal dominance in larger arrays encourages serial processing consistent with normal eye-movement patterns.
- o In most multiple channel situations, graphic coding should be used (e.g., dial or "pie-chart" graphics with designated "signal" sectors, moving bars with designated tolerance levels, etc.). More detailed information should be made available in ancillary alphanumeric form (perhaps "on demand").
- o Insofar as possible, spatial uncertainty in displayed context should be kept to a minimum. That is, when the number of sites at which an event or signal may appear becomes very large or infinite (e.g., geographical territory), some structuring should be imposed.
  - The problem is that unaided search will become biased toward higher probability sites to the exclusion of others, and may become erratic.
  - Structuring the context (or the search process) can help reduce such effects. For example, simplifying the spatial organization of sites, sectoring the territory, or providing a cuing "window" highlighting a defined local area which moves systematically over the entire territory at appropriate intervals

can serve this purpose with progressively greater effectiveness.

- When a clearly defined structure already exists in the context to be monitored, as in vehicular or materials flow routes, that structure need only be preserved in a form consistent with the actual organization (schematics, flow diagrams); it need not preserve detailed geography. Explicit search cues (arrowing, highlighting) might also be incorporated as noted above.

o When there is no spatial uncertainty (i.e., a single channel), explicit cuing may be useful to offset a similar uneven distribution of attention over the temporal domain.

o Events or event features that constitute signal conditions should be coded with several considerations in mind. Since these considerations are sometimes incompatible, their relative importance for the specific task objectives must be carefully weighed. Considerations include:

- Alerting properties of the code (e g., auditory "annunciators," flashing, high contrast, color, or other forms of visual "highlighting" are all well recognized as attention enhancers).
- Uniqueness or discriminability of the code. This becomes particularly important when, as a class, signal events need to be recognized quickly as such. One should not, for example, use similar highlighting to designate signal events and material that is currently being processed routinely (see also discriminate/compare, filter/ignore).
- Informativeness or information content represented in the signal code. In many monitoring situations it is important for the operator, once alerted to the presence of a signal condition, to be directed quickly to key diagnostic or even response information. Some of this information may be carried by the signal code itself. However, the more informative the code, the less well it is likely to accomplish its other purposes. Thus it is usually best not to convey more than the most critical, molar distinctions in the signal code (see also identify/recognize).

o When critical events and event patterns are causally linked in ways that produce multiple concurrent or closely sequenced signals, displays should be designed to minimize redundancy in the alerting code while representing (preserving) the causal or sequential features of the events.

- Once alerted, the operator needs information to assist in the efficient search for diagnostic or response information. Multiple "alerts" can obscure useful information and exacerbate the difficulty in processing it.
- Preserving event sequence information, for example with an "instant replay" feature, can be useful for diagnosis, particularly with graphic coding.

o When monitoring complex automated processes for which signal states are neither discrete nor clearly defined, operators must have a good working knowledge (accurate "mental model") of the controlled process. Display design can enhance this understanding through judicious use of graphics, extrapolation or trend depiction, and other aiding techniques (see processing operations 9.0 - 17.0).

- The primary display should be limited, however, to the most fundamental dynamic information (e.g., current status of key events in schematic representation of the system context). Other information should be available on demand.

- o Where signals are well-defined and mapped 1-to-1 with responses in rule-based processing, coding should be designed to maximize the "automaticity" of processing (see also discriminate/compare, filter/ignore, identify/recognize).
  - Generally this means using an unequivocal representation of signal events, consistent pairing with responses, and extensive overlearning.
- o Principles that promote simple monitoring (i.e., all of the above) are often somewhat incompatible with those involving more refined or complex mental processing of detected signal states (e.g., discriminate/compare, estimate, evaluate, etc.). For example, simplifying the structure of a complex spatial context aids monitoring at the expense of event pattern identification or comparison (see 18.0 complex interaction, below).

9.0 REMEMBER

Definition. Encoding and storing information mentally for later retrieval in either its literal (displayed) or some processed form (e.g., its sense or meaning). Involves somewhat different principles when retention is for relatively brief time periods (seconds, or at most, minutes) vs. longer intervals (the short-term memory or STM vs. long-term memory or LTM distinction).

- o Examples: retaining defining characteristics of an event observed on a situation display for look-up in a supplementary table (STM); storing an identification code for keyboard entry (STM); remembering a set of computer commands, decision options, processing rules (LTM); retaining the meaning of the contextual configuration, symbol designations, military doctrine, etc. (LTM)
- o Typical objectives: accuracy of retrieval and translation into output (response), efficiency in other mental operations

Display Considerations.

- o Coding
- o Formatting
- o Persistence

Design Principles.

- o Due to the fact that STM is severely limited and resource-demanding, the operator should never be required to retain more than 5-7 items for more than a few seconds, and that only under fairly simple processing requirements.
  - Wherever possible, the information should be preserved on the display until acted upon.
  - Insofar as other requirements permit, information used to elaborate upon events on a coded graphic display should be presented immediately adjacent to the event symbol.
  - The operator should never be required to perform a sequence of operations on the same stored information unless that sequence is so well established that it is "automated" (i.e., having used the stored information, the operator should never have to refer back to it without the benefit of "refreshment" from the display).

- The simpler or more direct the translation from mental storage to response, the fewer errors will occur; hence coding of the to-be-stored information on the display should take response requirements into account.

o The key to LTM enhancement is organization of to-be-stored (learned) material and building upon that which is already in storage (including "metaknowledge"). This has a number of display implications.

- Use coding schemes that are consistent with population stereotypes, natural language, and other pre-existing universal associations. In some cases it may be necessary to determine these associations empirically for the user population (see below).
- Graphic display is particularly useful for representing complex relationships among events (see also identify/recognize, perceive). Such representation should preserve the literal or conceptual relationships as directly as possible (e.g., spatial relations should be represented spatially; similarity relationships may be depicted spatially, by "network" diagrams). Flow diagrams, decision trees, maps, link diagrams, semantic networks, etc. are all effective.
- Organization of material that is not "naturally classified" should make use of familiar frameworks such as the alphabet and number systems, outline or hierarchical format, even a familiar spatial structure. Whatever scheme is used, however, it must be used consistently for the represented material (e.g., never switch unnecessarily from an alphabetical to a numerical representation of the same event set).
- Knowledge of the individual or collective user's typical way of conceptualizing or organizing the to-be-remembered material (mental model, subjective classification) can be extremely helpful in designing a structure. Where feasible, customization (or an operator, team, or entire user population) should be considered. Techniques exist for gathering such information efficiently.
- Retrieval of the stored information is sensitive to many of the same principles as storage. However, it is important to recognize that access to stored information also depends on specific retrieval cues (form in which a request is presented). For example, an operator is less likely to make an error in reporting current enemy positions if cued by position (is there an enemy unit in X position?) than by event (report all enemy positions).

10.0 ESTIMATE

Definition. Producing an approximate value for an event, context, or process state -- or for metaknowledge regarding that information -- in quantitative or occasionally qualitative terms, using primarily intuition (judgment, heuristics, "fuzzy logic," etc.) rather than systematic analysis. May apply to past, present, or future states, and is usually an important aspect of closely related choose/decide, evaluate, and integrate/organize/aggregate operations.

o Examples: judging the number or strength of deployed enemy units; establishing approximate location or heading of an unidentified object, or the probability that it poses a threat to a friendly position; expressing level of

confidence in a diagnosis or the reliability of an information source
- o Typical objectives: speed, gross accuracy (particularly in avoidance of systematic biases)

Display Considerations.
- o Coding
- o Formatting (for response as well as input information)

Display Principles.
- o Graphic coding encourages holistic, rapid, intuitive processing. Therefore, it is particularly useful for many estimation tasks. For example, pie charts are effective for estimations of proportion, line charts for trends, bar graphs for comparisons, etc. However, one should use such displays sparingly unless estimation is virtually the sole ongoing function of the operator (e.g., monitoring multiple information sources for gross anomalies or critical patterns).
  - Graphic coding is often space-intensive, and multiple displays conveying different kinds of information can be distracting (competing among each other for attention). Thus they are usually best reserved for "on demand" usage and for continuous display of only the most critical state information. (The exception, as noted above, is where monitoring is the operator's sole function, in which case the competition for attention is a positive feature).
  - Graphic coding is an effective way to overcome certain heuristic processing biases such as the common tendency to focus on some information sources or events to the virtual exclusion of others or to weight familiar (or expected) events more heavily than atypical ones. It can help offset biases involved in the operation of selection (see also integrate/organize/aggregate). Thus it can improve the quality of "intuitive" estimates.
- o Literal representation of multiple events, as in a battlefield situation display, yields reasonably good estimation performance provided the identifying features are clearly discriminable and simple (see also discriminate/compare, identify/recognize). Unaided estimates of absolute or relative event frequencies, spatial distribution, and other "descriptive statistics" are not seriously biased. Thus there is little point in recoding them into another graphic form unless further processing is required. However,
  - Estimation of temporal distributions, trends, etc. is biased due to memory limitations (see remember operation); therefore such estimates benefit from aiding/recoding.
  - Estimation requiring inferences from observed events is also biased (see correlate and integrate/organize/aggregate operations for explanation and recommendations).
  - Requiring overt (e.g., numerical) response improves estimation. For example, if an operator must make decisions based on the apparent relative strength of forces, overt estimation of friendly and enemy forces will improve the decision. Thus displaying an "estimate" instruction can be useful.
- o Numerical, as well as alphanumerical and to an extent textual coding, encourages serial, rule-based processing (the antithesis of estimation). However, operators can make reasonably good estimates from such information under certain circumstances.

- Estimates of "descriptive statistics" (average, variability, etc.) for items displayed in a structured array (list, table) or even in rapid succession is fairly unbiased. Lags of even a few seconds between serial items, however, will produce distorted estimates; thus serial items should generally be preserved for estimation during collective review. Of course, estimating "inferential statistics" is subject to the same biases noted above.
- A literal (unstructured) format seriously hampers estimations based on numerically or alphabetically coded information. For example, numerical values (e.g., reliability values) attached to enemy units scattered over a situation display are not easily averaged, and their presence may even inhibit simpler estimations, such as the total number of units.

o Estimation of movement, trajectory, target and other higher-order functions from displayed information is subject to distortion through simplification (e.g., overweighting linear components). Thus it is useful to preserve as much historical information as possible on the display.

o Displaying structured response options in a systematic format (e.g., rating scales with appropriate anchor points) promotes consistency and precision of estimation.

- The structuring format should be matched to the "mental structure" and precision level characteristic of human judgment in the domain of interest. For example, humans rarely are able to describe differences among complex stimuli reliably using more than 5-10 dimensions, and they rarely make probability or percentage distinctions finer than 5% or 10%. A structure affording greater precision than that is thus unnecessary and may even prove counterproductive. (Guidance on rating-scale principles can be found in any standard psychometrics text, but the particular format used should be developed and tested empirically for the specific estimation task and user population.)

11.0 CALCULATE

Definition. Carrying out simple arithmetic operations. Naturally, complex computations will be carried out automatically, but simple calculations may not be.

o Examples: calculating the time between the expected occurrence of two events, determining the ratio of the number of attacking targets to the number of defensive assets

o Typical objectives: speed, minimization of demand on mental processing resources

Display Considerations.

o Tabular versus graphical presentation of data

o Level of precision

Design Principles.

o If graphics are to be used then bar graphs are usually most appropriate.

- Bar graph displays are particularly useful if a very approximate result is sufficient; tabular displays are needed for more precision.

o Any more than the simplest arithmetic operations are taxing, slow, and prone to error.

- o On-screen calculating devices can be effective if set up so that the operator has only to point at the numbers on the screen and the desired function in order to accomplish the calculation.
- o All quantities involved in the calculation should be visible simultaneously.
  - No calculations should require remembering numbers.

12.0 INTEGRATE/ORGANIZE/AGGREGATE

Definition. Establishing a collective interpretation, result, or structure for multiple information items which may stem from a variety of sources, come in various forms, and vary in quality and complexity. Typically, but not always, involves identifiable organizing principle (rule, algorithm, heuristic) and some form of "aiding." May require inductive and/or deductive reasoning. Usually the precursor to choose/decide, evaluate, generate/create operations; often involves calculate, correlate, estimate, remember operations.

- o Examples: readiness estimation, threat diagnosis, inference of enemy tactics or objectives, cost/benefit analysis
- o Typical objectives: appropriateness of processing (e.g., vs. "optimal" rule), accuracy or sufficiency of result (vs. reality or "ground truth"), contribution to understanding (e.g., new insights, hypotheses), timeliness

Display Considerations.

- o What to display and at what level of detail
- o Formatting
- o Coding

Design Principles.

- o When events occur over time and aiding is minimal (i.e., operator performs required function manually or "intuitively"), it is important to preserve the record of component event information for collective review at the time of processing.
  - An important limitation on collective processing over time is distortion in the "mental record" of past events through selective encoding, forgetting, or retrieval biases. Undue weight is given to "available" items, and inference is confused with memory. Preserving the actual record reduces such distortion.
  - The operator should be afforded the option to review the target events sequentially or simultaneously (see discussion below).
- o When information is available simultaneously (on review or original display) and aiding is minimal, the principal display-related limitation is extraction. Therefore, all issues discussed under identify/recognize, discriminate/compare, filter/ignore, and perceive/interpret pattern operations become important. That is, any extraction bias will distort the result of integrative processing. Thus the display should promote ease of identification of the to-be-integrated (target) event classes, and discrimination of those from other events and context elements.
  - Problems arise as overall complexity and number of displayed events (display load) increase. A related problem exists when the events or event features that constitute the target set change frequently (what is now relevant was previously irrelevant). In both cases, the demand on available

mental resources increases and extraction, integration, or both may suffer.

- Selective highlighting of the target set, preferably under the operator's control, is one solution to this general problem.
- Another solution, in essence a low level of aiding is to organize the material on the display in ways that allow unambiguous access to target items. This generally means having available alternative classification schemes keyed to particular features. The operator may thus "call up" the target category. If used in conjunction with a comprehensive display, however, there is a potential cost in adding to the overall display load. If used instead of a comprehensive display, other information (e.g., spatial context) is sacrificed. Trade-offs should be weighed carefully.

o Formatting and coding may influence actual integrative processing in addition to the extraction of salient events. Knowledge of how and when this happens, however, is sparse. Some research supports the following:

- Graphic display encourages holistic, rapid, "intuitive" integration. There is a tendency to average information whether or not that is the appropriate algorithm. However, it also encourages consideration of all available cues in the integrative product. Certain kinds of comparative judgments can be improved with pie, bar, or line graphs, but only when relatively few variables are to be considered. Also, specific formats can over- or under-emphasize particular features. In general, graphic display is useful when an operator must make quick judgments, estimates, or predictions under time pressure.
- Tabular display using alphanumeric coding promotes serial, rule-based, "analytic" integration. This type of processing is slower but, if an appropriate algorithm is available to the operator, may yield higher quality results than the graphic mode. However, in the absence of an algorithm and sufficient time, the tendency is to base judgment on a selected portion of the total data set, and not necessarily the most informative items. Serious biases (e.g., "conservative" opinion revision) can result. In general, then, the tabular format should be used sparingly for unaided integrative processing, reserved for rule-based, deliberate operations.
- Transfer from graphic to alphanumeric display may be more efficient than the reverse. That is, operators familiar with the algorithmic, serial approach fostered by tabular displays have more difficulty adjusting to the holistic, graphic mode than do those familiar with graphic mode in adjusting to the tabular format. Again, this supports primary use of the graphic format supplemented by tabular display, particularly under stress. (Evidence on this point, however, is still tentative.)
- Graphic display can enhance integrative processing by promoting the understanding of automated processes and application of optimization rules. Flow diagrams, schematics, decision trees, etc. combat logical errors, omissions, and the formation of faulty mental models. However, there are important exceptions to this principle. (1) Graphic display is less important for expert than novice (or less proficient) operators. (2) Graphic display presumes accurate and interpretable representation of the underlying process or rule. (3) Graphic display is dependent on the complexity of the underlying process or rule, and "naturalness" of spatial representation.

(Simple processes or ones not easily conceived of in spatial or graphical terms may be better conveyed using text). In short, graphic representation must justify its "cost" in display load on the basis of efficient communication of complex process information to the operator. There is currently no means of estimating this cost/benefit ratio short of an empirical test on a sample of the user population.

- o When all or part of the integrative processing is automated using an algorithmic aid (Bayes rules, cumulative proportions, linear regression model, weighted sum, etc.), the output of that process should be displayed in a manner consistent with the operator's understanding and use of that information.
  - If the operator is obliged to choose among options (see choose/decide), the output should be organized by options for ease of comparison.
  - If the operator has an override or sign-off responsibility, user acceptance (as well as confidence and understanding) becomes a critical consideration. Thus, easy access to the raw data and various processing stages should be provided. Error or reliability estimates should be included for both stage and final outputs. Since it is impossible to anticipate what information a particular operator will need in a particular situation, all such process information (with the possible exception of output reliability estimates) should be on demand to minimize display load. Format should be consistent with principles set forth above.
  - In some cases, it may be useful to provide a "what if" capability under the operator's control. That is, the opportunity to alter parameters or assumptions in the aiding algorithm can enhance user understanding and acceptance as well as the usefulness of the result. (Evidence to date, however, favors the improvement or increase in understanding and acceptance rather than actual improvement in performance. Manual adjustments rarely improve automated integrative processing. See, however, choose/decide operation, below). When "what if" provisions are available, spread-sheet formatting is an effective display medium.
  - If the output of the aiding process is to be applied to a problem represented in graphic form (e.g., intercept decision), it should be displayed graphically (e.g., kill window); if it is to be applied to a numerical problem, it should be displayed numerically, etc. In short, the operator should be required to perform minimal transformation of the output in using it and seeing the results of its use.

13.0 EVALUATE

Definition. Establishing the condition or status of an event, event pattern, context, or total situation on one or more well defined subjective scales. May be expressed in quantitative or qualitative terms and reflect varying degrees of subjectivity.

- o Examples: assessing the threat posed by an enemy unit or by the overall current situation, determining the state of readiness of friendly forces, assessing the level of success achieved in a current or past engagement
- o Typical objectives: accuracy, precision, speed

Display Considerations.

- o Precision or detail of displayed information
- o Amount of information displayed
- o Coding and format

Design Principles.

- o Since evaluation is generally the end result of an integration/organization/aggregation process, all principles described for this operation apply.
- o A number of well-established biases threaten the quality of unaided (intuitive, knowledge-based) evaluative judgments. Therefore, whenever feasible, algorithmic aiding should be used to simplify evaluative processing. Human judgment should be reserved for components of the process for which no algorithm exists (e.g., the increment in threat posed by an unfamiliar configuration of hostile units in light of an updated intelligence report). When judgment is required, the display should have the following characteristics:
  - Limit the number of features of the to-be-evaluated events of patterns to those of direct relevance to the judgment.
  - Rely minimally on human memory for relevant items (i.e., display relevant information).
  - Use the same response scale for all similar evaluative judgments (e.g., a seven or nine-point rating scale for all readiness or threat estimates; a probability scale for all uncertainty judgments, etc.).
  - Organize the material for simple comparative rather than absolute evaluative judgment where time permits, the number of items is relatively small, and items are complex (multidimensional).
  - Use graphic format/coding for very rapid evaluation of multiple items characterized by few relevant dimensions.
  - In general, match the level of precision and detail of the displayed information to the capability of the operator: if the typical operator is incapable of making more than a half-dozen distinctions on a particular feature, which is often the case, the display should not present more than perhaps 10-12 levels of that feature.
- o It is important to recognize that evaluative judgments are particularly sensitive to display parameters of the sort illustrated above. Thus the designer should conduct some form of sensitivity analysis on the task and the human operator early in the design process. That is, one should determine how much the system output benefits from progressive levels of precision in judgment, and how much human judgment benefits from progressive levels of display precision. Building greater precision into the display than the human can handle or the system needs can actually degrade performance (e.g., it can add unnecessary complexity, and can inflate operator confidence unjustifiably). Such analyses also can be helpful in determining where aiding offers the most potential pay-off.

14.0 GENERATE/CREATE

Definition. Producing multiple interpretations, strategies or response options based on event, context, and process information. May involve intuitive or analytic (rule-based) processing, and is closely related to the integrate/organize/aggregate operation.

- o Examples: determining all the plausible purposes or objectives of an observed enemy maneuver, identifying the set of targets that are within range of available weapons, specifying all the strategic countermeasures that are likely to be effective against a particular type of attack
- o Typical objectives: completeness, accuracy, timeliness

Display Considerations.

- o Coding
- o Formatting
- o Aiding features

Design Principles.

- o For the most part, the same principles as described under the integrate/ organize/aggregate operation apply. However, the unique concern in the generate/create operation is combatting the human bias toward premature resolution, overselection and simplification (e.g., failing to consider more than one alternative). Display features can help as follows:
  - Display request for additional items (e.g., "more?") after each interpretation is entered, and required active sign-off ("no") before proceeding with the program.
  - Provide operator access to a variety of different methods (especially graphic modes) for displaying the same information, since different modes encourage somewhat different processing and perspectives.
  - Avoid concurrent display of more than two perspectives on the same data -- an effective possibility is to use one primary display plus a "window" for sequential viewing of alternative perspectives.
  - Maintain a current display list of all options generated by the operator and provide editing capability on those items. It may also be useful to dedicate display space for temporary storage of tentative items prior to entry into the current list.
  - When generation of each alternative involves a complex sequence of well-defined steps, display a record of the operator's process (including partial solutions) and the next required step. That is, decompose the problem and "walk" the operator through it in the most efficient manner.
  - If there is a reasonably limited number of total possibilities from which the present situation offers a subset, it is useful to display the entire set in some consistently organized fashion for systematic exhaustive scanning. Tabular presentation with scrolling capability encourages such scanning. This approach becomes unwieldy when the total set exceeds 50 - 60 items, although the maximum depends on trade-offs between completeness and timeliness goals.
  - If a total set is presented for scanning, coding should be as "natural" as possible to minimize interpretation difficulty and confusions (e.g., natural

language, stereotypic symbols, etc.). Prototype designs should be pretested empirically, and easily confused items modified, before a coding scheme is implemented. (See discriminate/compare, identify/recognize operations.)

15.0 CHOOSE/DECIDE

Definition. Selecting from among recognized set of alternatives the action or strategy to implement. (Technically, includes all judgment processes leading up to action selection, but for present purposes pre-decisional processes are treated separately -- see especially estimate, evaluate, generate/create, integrate/organize/aggregate operations).

- o Examples: choosing firing order for missiles, deciding which position to defend most heavily, selecting a target
- o Typical objectives: maximizing the decision outcome, achieving a satisfactory outcome under limited time and/or information

Display Considerations.

- o Coding
- o Format
- o Amount, type, and precision of information displayed

Display Principles.

- o Choice alternative should be presented concurrently in a form that permits easy comparison (see discriminate/compare).
- o Graphic format is particularly useful when a number of comparisons must be made in a very short time period and selection is largely ordinal. It should be recognized, however, that graphic representation is limited with respect to the number of features and level of detail that can be conveyed; hence it is most effective when the decision options involve relatively few salient characteristics or decision aiding has made them appear so (e.g., threat values or system confidence levels have been machine calculated).
- o Tabular presentation of options is preferable when precise, quantitative comparisons must be made on multiple dimensions, especially if the salient dimension changes from problem to problem or at various stages of processing.
  - As noted in previous principles, tabled information can add substantially to display "clutter" and should therefore not be displayed continuously unless it is needed frequently. In other cases it is best made available on demand as a supplement to the simpler and cruder graphic display.
- o In complex (multi-dimensional) choices, structure afforded by the format -- graphic, tabular or a combination -- can be extremely helpful. A common format for this purpose is the decision tree, which organizes information relevant to the various options in a hierarchy of "branches" and "twigs." Providing the operator a means of simplifying the display ("pruning" the tree) enhances its usefulness.

o When aiding capability includes future projections or "what if" computations, key assumptions in the model (other than those entered by the operator) should be displayed. For example:

- In graphic display of a missile trajectory or intercept point, the function underlying the projection is usually represented directly in the "track."
- In statistical projections or tabular display; however, the function is not directly apparent and -- if relevant to the decision -- should be presented explicitly in terms meaningful to the user.

o Error, reliability or confidence estimates associated with displayed events, data, or output of a processing aid should be displayed whenever it differs across choice options. Otherwise it is irrelevant to the decision and should be omitted.

- Representation of such uncertainty information should be consistent with the mode of the primary information (e.g., if it signifies uncertainty in target location on a map, it might be the size of a circle around the target symbol; if tabled intercept time, it should be ± time units).

o The principal <u>coding</u> issues are those discussed in conjunction with pre-decision operations (see above). By and large, they are more critical for such preparatory processing functions than for <u>choice</u> per se: hence where trade-offs are involved, coding should be displayed to enhance whatever judgment (<u>discriminate/compare</u>, <u>integrate/organize/aggregate</u> operations, etc.) is most instrumental in arriving at the option set, rather than to optimize choice among options.

16.0 MANIPULATE

<u>Definition</u>. Acting on a graphically-represented event or object in order to modify it or what it displays in some fashion. Used as part of direct-manipulation interface.

o Examples: changing the size of a display window in a multi-window environment, altering the dimensions of information displayed about a particular object, indicating that a target is to be assigned to a category such as friend or enemy

o Typical objectives: accuracy, economy of space usage, minimization of mental workload

<u>Display Considerations</u>.

o Display resolution

<u>Design Principles</u>.

o Continuous visual feedback of the state of the object should be provided as the state is changing.

o Consistency in the responses of different types of objects is very important. The method for changing the dimensions displayed about an object should be the same for all objects; a common method for changing the size of an object should be used.

o As a rule, control of cursor movement on the display (by mouse, cursor keys, joystick, or other manual devices) should be represented on the display screen in compatible, consistent analog form.
  - An exception is where small regions must be located or small objects selected. Here it is often desirable to incorporate a "homing" feature such that the cursor is drawn to the target once the cursor enters a predefined tolerance region.

o Any action represented in the display should be revisable (capable of being returned to its previous state).

17.0 COMMAND SYSTEM

Definition. Once the operator has decided on a course of action, there is still the problem of indicating the action to the system. This can be accomplished by commands or by interacting with dialogue boxes. A dialogue box can contain a menu of choices as well as sets of exclusive or nonexclusive options.

o Example: the operator has decided to fire a missile from one of three possible batteries and must choose two of four possible firing options

o Typical objectives: speed, accuracy, providing a final verification for important actions

Display Considerations.

o Display quality

o Display size

Design Principles.

o Command interface characteristics can affect performance (see also choose/decide, integrate/organize/aggregate).
  - Key considerations include consistency, congruence and familiar mnemonics.
  - Hierarchical command structures are easy to learn and are useful for reducing the interfering effects of material presented before and after the to-be-learned material (the well-established phenomena of "proactive" and "retroactive" inhibition). A hierarchical command structure is one in which the most general semantic groupings of commands are indicated by the first keystroke, a second level (if necessary) by the second keystroke, and so on. For example, all commands having to do with preparing to fire a missile could start with one key whereas all commands having to do with communications could start with a second. Hierarchical command structures often trade off ease of use with the number of keystrokes. In general, the time to press an additional key (about .28 seconds for an average typist) is considerably less than the time to recall a less well-structured sequence.
  - Since command sequences are hard to remember if not consistently used, high and continuous levels of training are highly desirable.

o Interaction can be enhanced through use of dialogue boxes according to the following principles:

- One way for the interface to allow operators to indicate their choice of action to the system is to present a dialogue box or series of dialogue boxes on request. An example is shown below in Figure 3:

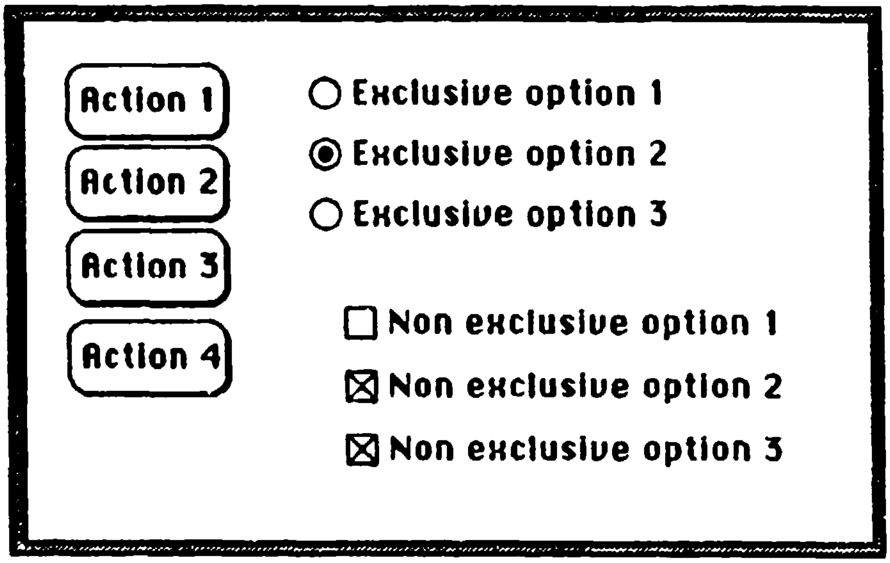


Figure 3. Operator choice dialogue box.

- It is desirable to distinguish visually between different types of buttons. In this example, buttons that execute an action are indicated as round-cornered rectangles, buttons that represent a group in which one and only one option can be selected are represented as circular ("radio") buttons, and buttons in a group in which it is possible to select any number as possible options are represented as square check boxes.
- A menu-based selection system is simply a special case of a dialogue box system in which only buttons leading to actions are present. One action is to present another dialogue box (menu).
- Just as with commands, hierarchical grouping of choices in dialogue boxes is desirable. That is, when there is a large set of possible options, logically related sets of options should be grouped. Semantic grouping should be aided by displays that result in perceptual grouping congruent with the semantic grouping. Perceptual grouping can be achieved by using different colors for different groups, graphic frames or outlines around each group, or spatial proximity (see also <u>perceive/interpret pattern</u>).

18.0 COMPLEX INTERACTION

Definition. Realistic C^3I tasks require multiple combinations of identifiable operations on displayed information in patterns and sequences that are only partially predictable and under the operator's control. Such combinations may involve incompatible display principles.

- o Examples: identifying and remembering the most critical of a set of events all of which are coded for ease of location or pattern perception, making quick estimations and following explicit algorithms (e.g., calculations, analytic rules), filtering and monitoring, monitoring and processing (detected signal events)
- o Typical objectives: achieving optimal or at least acceptable combined performance, user acceptance

Display Considerations.

- o By definition, interactions and trade-offs among component principles.

Design Principles.

- o Identify and weight the component operations required by the actual or candidate system architecture. Weighting should consider a combination of frequency and importance for overall system goals.
  - Review display principles applicable to each operation category and identify conflicts or incompatible recommendations.
  - If incompatibility is clear, priority should be accorded the higher-weighted operation.
  - If weights are fairly equal, the potential seriousness of violating one or the other principle should be considered.
  - Occasionally, compromise solutions may be found in which both principles are violated but to a limited degree (multidimensional graphic coding is a good case in point -- see identify/recognize).
- o Consider the combined effect of conforming to individual display principles on the following overarching principles:
  - Consistency. Insofar as possible, represent the same kinds of information in the same manner, and avoid using similar conceptual or perceptual coding dimensions in representing very distinct objects or events. Inconsistency breeds confusion and increased mental demands.
  - Minimization of display load and "clutter." Other things being equal, the less information displayed at any given moment, the better. Information that is needed only occasionally should not be displayed continuously; redundancy should be reserved to ensure against only the most critical errors; only the most salient context should be displayed. The more crucial or stressful the situation, the less able the operator is to process information -- hence the more harmful irrelevant (capacity-draining) information will be, the more easily confusions will occur, and the less use will be made of complexities and details.
  - User control and direct manipulation. Insofar as possible, it is useful to permit the operator control over the access to information that is only needed occasionally or is of minor importance. The danger in external programming of such information (an alternative means of avoiding clutter and overload) is failure to recognize individual differences in the execution of

similar operations. Different individuals often feel the need for different kinds of information even in performing an identical rule-based task! Access control, as well as manipulability of displayed items, can have the added benefit of enhancing the operator's confidence in the involvement with the automated facets of the system. The main exceptions to this principle are circumstances under which (1) it is seriously disadvantageous for the operator to deviate in any way from one prescribed approach, (2) the operator needs to be alerted to, reminded of, or focused on a critical situation, (3) time pressure does not afford the luxury of deliberation in selecting information.

- User acceptance. There is little value in display features that operators ignore, misunderstand, or lack confidence in. Involvement of users in the design process, control over information access (see above), and aids to understanding automated processes (see also integrate/organize/aggregate) promote acceptance.
- Minimization of short-term memory load. The well-established limitation of humans to retain more than about seven items in "working memory" at any given time, the amount of "mental resource" required to keep even this handful active, and the speed with which unattended items are forgotten or distorted, all argue for relieving the operator of this function insofar as possible. This principle is particularly important in the multiple-operation context since the output of one operation must often be retained in performing another (e.g., identify/recognize, integrate/organize/aggregate).
- Recognize processing demands. Many of the operations performed on displayed material, including ultimate responses, draw upon the operator's limited store of "mental processing capacity." It usually requires conscious effort to ignore a displayed element, and in some cases even that effort is unsuccessful. Thus any unnecessary addition to the overall set of operations required can be detrimental to performance if the overall demands are reasonably high. On the other hand, some level of mental activity is necessary to maintain alertness and involvement. While no clearly established "optimal value" has yet been determined, useful means do exist for measuring subjective mental workload. In exploring design modifications or evaluating system prototypes, it would be well to include subjective mental workload measures among the considerations.

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